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*MODELS FOR TRIP PREDICTION
DEVELOPED FROM FOURTEEN
URBAN AREAS*

*SEPT. 1965
NO. 15*

*Joint
Highway
Research
Project*

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

by
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Technical Paper

MODELS FOR TRIP PREDICTION DEVELOPED

FROM FOURTEEN URBAN AREAS

TO: G. A. Leonards, Director
Joint Highway Research Project

September 24, 1965

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project C-36-54DD
File 3-3-30

The attached paper "Models for Trip Prediction Developed from Fourteen Urban Areas" has been prepared for consideration for presentation at the January 1966 meeting of the Highway Research Board. The authors, James J. Schuster and Harold L. Michael, have summarized the research report on this subject previously presented to the Board.

The paper presents nine mathematical models developed on the research using data from fourteen urban areas, standard metropolitan statistical areas (SMSA). These models should be useful in developing travel pattern studies for other SMSA's by synthesis.

The paper is presented to the Board for approval of submission for possible presentation and publication.

Respectfully submitted,



Harold L. Michael, Secretary

HEM:bc

Attachment

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MODELS FOR TRIP PREDICTION DEVELOPED
FROM FOURTEEN URBAN AREAS

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File 3-3-30

Draft Copy

Subject to Revision

Submitted for Review

to Highway Research Board

Purdue University
Lafayette, Indiana
September 24, 1965

Models for Trip Prediction Developed

from Fourteen Urban Areas

INTRODUCTION

A standard metropolitan statistical area (SMSA) is defined (except in New England) as a county or a group of contiguous counties which contain at least one city of 50,000 inhabitants or more or "twin cities" with a combined population of at least 50,000. In addition to the county or counties containing such a city or cities, contiguous counties are included in a standard metropolitan area if, according to certain criteria, they are essentially metropolitan in character and are socially and economically integrated with the central city. In New England, towns and cities rather than cities and counties are the units used in defining standard metropolitan statistical areas. (1)^{*}

In 1960 there were 212 SMSA's in the United States of which 188 had a population less than one million. Of the 190 million people in this country in 1960, approximately 63 percent lived in those 212 areas. The location of the SMSA's are shown in Figure 1.

The optimum location and design of urban transportation facilities require a reasonably accurate estimate of the usage of each facility in the design year. Good estimates of this usage appear to be possible from a good knowledge of the current travel patterns of the city. Consequently many cities have conducted travel pattern studies, commonly known as

* Numbers in parentheses refer to entries in the list of references.

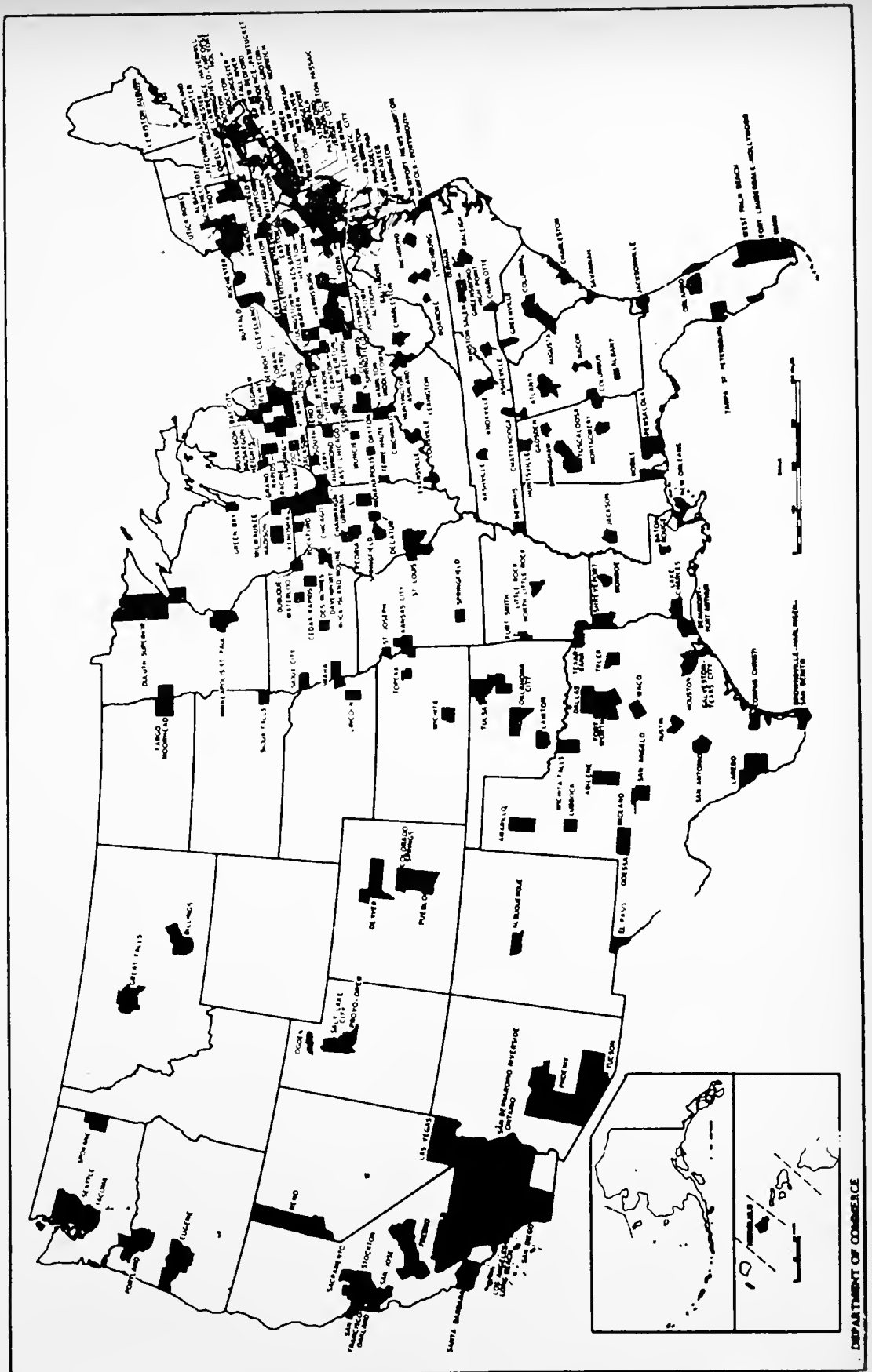


Fig. 1. Standard metropolitan statistical areas, 1960.

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origin-destination surveys. These time-consuming and expensive studies have resulted in an indication of a similarity of travel patterns in cities of similar size. Furthermore, it is generally acknowledged that travel of urban residents has many similar characteristics.

Synthesis of these travel patterns from characteristics of the city and its inhabitants has been the subject of considerable recent study. Each of these studies, however, has generally been performed in only one city and the resulting techniques have often not been satisfactory when applied to another city.

Several of the cities in the standard metropolitan statistical areas have had recent transportation studies, including origin-destination. The possibility existed, therefore, of analyzing the results of several of these studies in the hope that techniques and models for synthesizing the travel patterns of cities of similar size could be developed.

The purpose of this research was to develop a method for synthesizing urban travel patterns through an evaluation of various factors which affected travel characteristics in 14 different urban areas.

The study included an investigation of travel characteristics in MSA's less than one million population. This population classification was chosen because of the possible homogeneity in the factors affecting transportation facilities. Statistical analyses of data from the 14 cities were made to evaluate correlations in urban travel characteristics.

Urban vehicular trip patterns, truck trips, and traffic generation of the central business district were among the characteristics investigated.

STATISTICAL ANALYSIS PROCEDURES

One of the most useful tools available to the planner is statistics. Particularly in the field of trip prediction, the techniques of simple regression, multiple regression, and model evolution are extremely useful. One useful statistical measure is the square of the correlation coefficient. This provides a measure of the amount of variability of a dependent variable that is explained by the independent variable or variables.

The evolution of models from data using multiple regression procedures allowed the acquisition of maximum information from collected data. Established techniques were used to determine which independent variables should go into the final model. In all cases, the F-test was utilized to examine the amount of explained variation.

One element that must be considered in model evolution is the use of the final model. In planning studies it is often necessary to predict future trips from future land use areas. It is necessary to assume that the factors that affect present day trips will also affect future trips if a model evolved from present day trip data is used for trip prediction. Preference may therefore be given to certain variables which are expected to have similar influences today and in the future even though a best correlation coefficient may not be attained.

The general model evolved through multiple regression is of the following form (2):

$$Y_i = B_0 + B_1 X_{1i} + B_2 X_{2i} + \dots B_k X_{ki} + e_i$$

where:

Y_i = i^{th} observed value of the dependent variable

B_0 = parameter

B_i = parameter, $i = 1, 2, \dots k$

X_{ji} = i^{th} observation of the j^{th} independent, fixed variable, which could be an interaction such as $X_1 X_2$, X_1^2 , etc. $j = 1, 2, \dots j \dots k$ and $i = 1, 2, \dots u$.

URBAN TRIP PREDICTION DEVELOPMENT

General

To evaluate the possibility of estimating trip patterns of a city in a SMSA, data were obtained and analyzed from 14 such cities that had completed a transportation study.

For each of the 14 study cities there were five basic areas, the central business district, the 1960 city area, the 1960 urbanized area, the 1960 standard metropolitan statistical area, and the transportation study area. The organization that performed each transportation study delimited the central business district and the entire transportation study area. In all cases the latter area was larger than the city area and smaller than the SMSA.

In all cases the 1960 SMSA contained the largest population. The populations for four of the basic areas for each study city are listed in Table 1.

In the conduct of this research, data were obtained from the 1960 census and from the 14 transportation studies.

In addition to the many variables that were obtained from the census and transportation studies, many interactions were used in evolving the various models. Interaction is the differential response of one factor in combination with varying levels of a second factor applied simultaneously; that is, interaction is an additional effect due to the combined influence of two or more factors. (3)

Total Vehicle Trips in a Study Area

Total vehicle trips in a study area are comprised of both the internal and external one-way movements. An internal trip has both the origin and the destination within the confines of the delimited study area and includes interzonal trips and intrazonal trips. An external trip may have one or both ends of the trip outside the study area and includes external-internal trips (called local trips in this study) and through trips.

The model evolved for total trips was:

$$Y = + 142010 + 1.53441 X_1 - 8731.8 X_2 \quad (I)$$

where:

Y = total number of vehicle trips per day in a study area

X_1 = transportation study population

X_2 = percent of employed persons using public transportation to work.

TABLE 1
POPULATIONS OF FOURTEEN STUDY CITIES

City	Transportation Study	1960 SMSA	1960 Urbanized Area	1960 City
Charlotte	202262	272111	209551	201564
Chattanooga	241709	283169	205143	130009
Dayton	425000	694623	501664	262332
Denver	816700	929383	803624	493887
El Paso	268968	314070	277128	276687
Huntsville	73260	117348	74970	72365
Nashville	357585	399743	346729	170874
New Orleans	855551	868480	845237	627525
Omaha	296449	457873	389881	301598
San Antonio	586586	687151	641965	587718
Springfield	99020	131440	90157	82723
Toledo	405000	456931	438283	318003
Tucson	242550	265660	227433	212892
Tulsa	240419	418974	298922	261685
Range	73260- 855551	117348- 929383	74970- 845237	72365- 627525

The amount of variability (R^2) explained by this model was 96.9 percent with a sample size of 14.

Effect of Study Population and Area

The ratios of external vehicle trips to total vehicle trips and local vehicle trips to internal vehicle trips vary with the size of the transportation study population and area, as shown in Figures 2 and 3. The curves shown are least square fits of data obtained from the 14 study areas. It is easily seen that as the area increases, population increases, with the effect that fewer trips are included in the external portion of the survey.

It was desired to know if these two ratios could be estimated from the factors of population and area. The following models were evolved for this purpose:

$$Y_1 = + 0.4126 + 10^{-10} \left[0.0242 X_1 X_2^2 - 4644.2 X_1 - 11351 X_2^2 + 452.1 (X_1/X_2)^2 - 1576380 (X_1/X_2) \right] \quad (II)$$

and

$$Y_{11} = + 0.545 + 10^{-7} \left[- 0.02687 X_1 X_2 - 17.4 X_2^2 + 7.00 (10^{-5}) X_1 X_2^2 + 0.656 (X_1/X_2)^2 - 2774 (X_1/X_2) \right] \quad (III)$$

where:

Y_1 = ratio of external vehicle trips per day to total vehicle trips per day

Y_{11} = ratio of local vehicle trips per day to internal vehicle trips per day

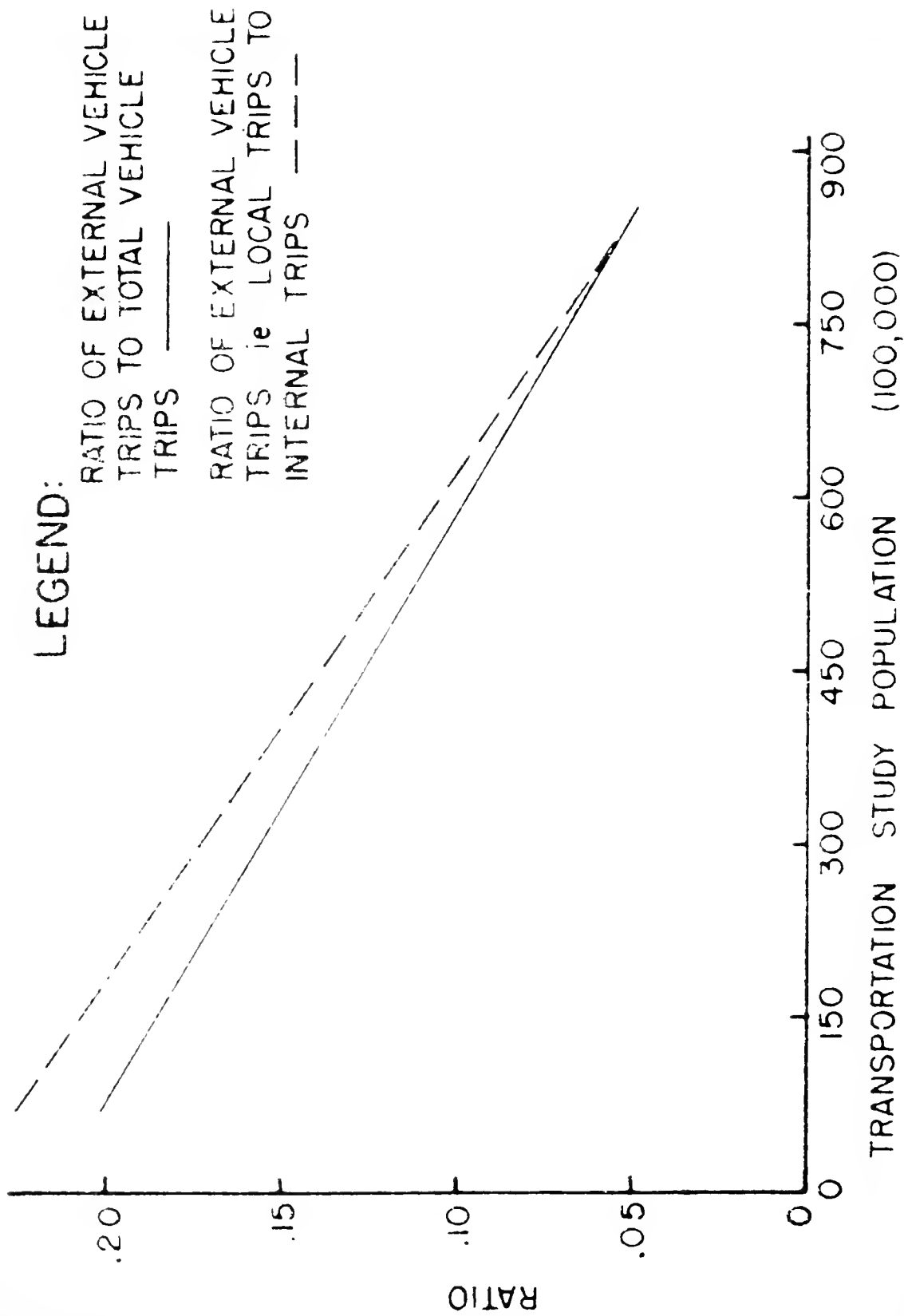


Fig. 2. Relation of external trips and transportation study population.

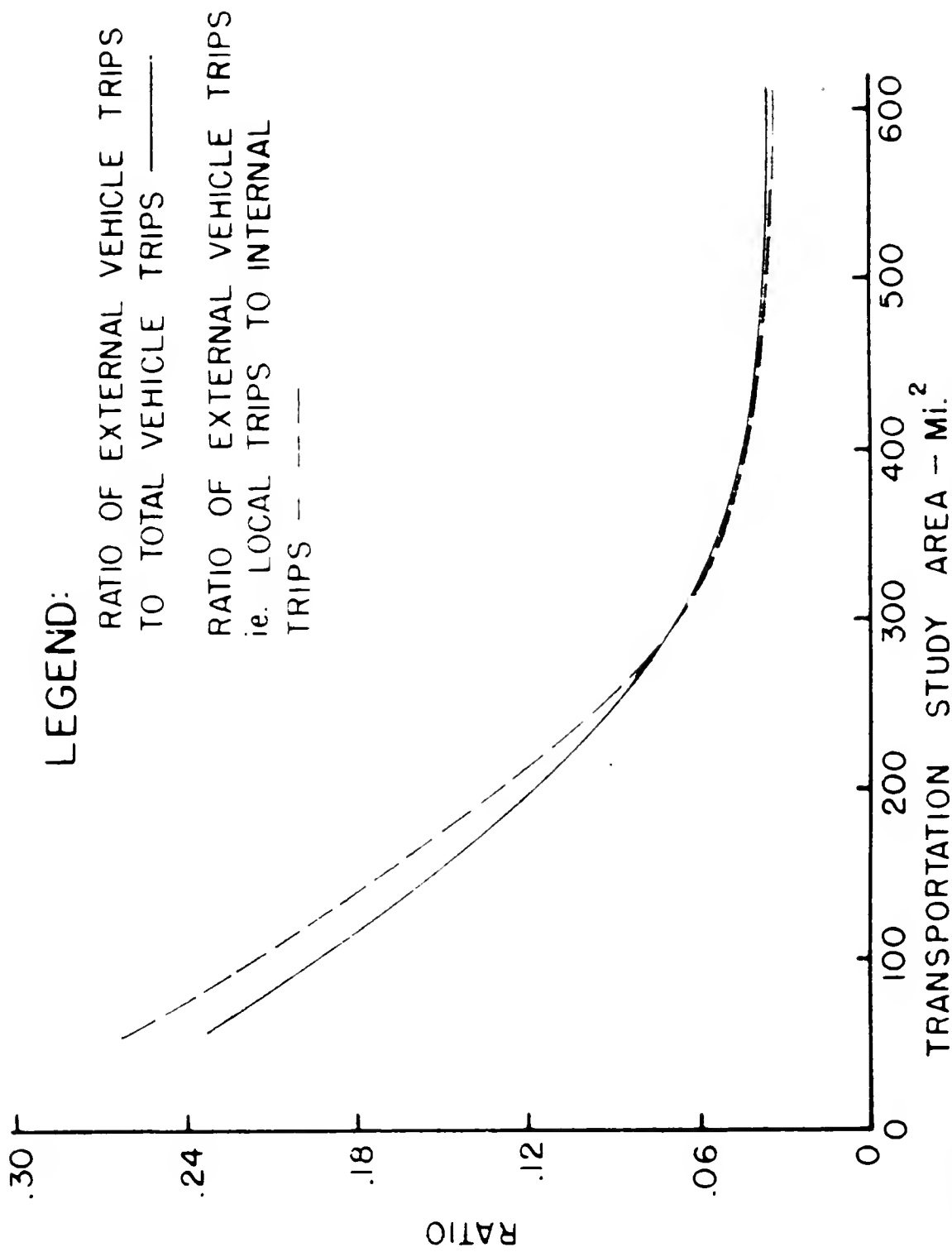


Fig. 3. Relation of external trips and transportation study area.

X_1 = transportation study population

X_2 = transportation study area in square miles

The amounts of variability (R^2) explained by these models were 87.5 percent and 85.8 percent, respectively with a sample size of 14 each.

Vehicle Trips to and from the Central Business District

The internal and external vehicle trips per day to and from the central business district consist of those trips that have either their origin or destination in that particular zone. Such trips were an average 73,556 for the 14 study cities and ranged from 22,855 in Huntsville to 119,640 in New Orleans. The following model was evolved:

$$Y = -39570 + 0.04948 X_1 + 41335 X_2 - 1443.9 X_3 + 1492.0 X_4 + 28.755 X_5 \quad (IV)$$

where:

Y = vehicle trips to and from the central business district per day

X_1 = transportation study population

X_2 = area of the central business district in square miles

X_3 = percent of employed persons using public transportation to work

X_4 = percent of employed persons who had white collar occupations

X_5 = the interaction of the area of the central business district by the transportation study population density.

The amount of variability (R^2) explained by this model was 94.4 percent with a sample size of 14.

Intrazonal Central Business District Vehicle Trips

The intrazonal central business district vehicle trips are those movements that have both their origin and destination within that particular delimited zone. The lengths of these trips are necessarily very short due to the small area of the district, which was less than one square mile for each of the study locations.

The following model was evolved:

$$Y = + 5790 + 6406.7 X_1 + 0.8432 X_2 - 1.18459 X_3 - 0.00017 X_4 + 0.01909 X_5 \quad (V)$$

where:

Y = intrazonal central business district trips per day

X_1 = area of the central business district in square miles

X_2 = transportation study population density

X_3 = median family income for the standard metropolitan statistical area

X_4 = interaction of transportation study population by the percent of employed persons using public transportation to work

X_5 = interaction of the transportation study population by the area of the central business district.

The amount of variability (R^2) explained by this model was 98.5 percent with a sample size of 14.

Study Zones

For the evolution of models for the number of vehicle trips per day attracted to and generated by a zone, the number of vehicle trips per day in both directions between a zone and the central business district, and the number of interzonal vehicle trips per day, 75 study zones, excluding the central business district, were chosen from 13 study cities. These were chosen on the basis of being representative of the entire study area.

Analyses, therefore, were made on the vehicle trips attracted to and generated by 75 zones, the vehicle trips in both directions between those 75 zones and their respective central business districts, and the interzonal vehicle trips within the cities. The resulting number of interchanges was 269.

Zonal Vehicle Trips

For the 75 study zones a model was evolved for the total number of vehicle trips per day attracted and generated by a zone. Total trips consisted of internal trips, external trips, and intrazonal trips. The following model was evolved:

$$Y = - 7655 - 1326.4 X_1 + 5.0602 X_2 - 0.01714 X_3 \\ + 43.416 X_4 + 7.2513 X_5 + 2.07 (10^{-6}) X_6 \quad (VI)$$

where:

Y = total number of vehicle trips per day attracted and generated by a zone

X_1 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone

X_2 = number of passenger cars owned in the study zone

X_3 = population of the entire transportation study area

X_4 = transportation study area in square miles

X_5 = transportation study density in persons per square mile

X_6 = three factor interaction of percent of population that are workers in a study zone by the number of people that are in the study zone by the number of cars that are in the study zone.

The amount of variability (R^2) explained by this model was 91.0 percent with a sample size of 75.

Zone-Central Business District Trips

A model for the number of vehicle trips per day in both directions between each of the 75 study zones and its respective central business district was evolved for the study cities. The following model was evolved:

$$Y = + 498 + 0.46257 X_1 - 96.700 X_2 + 0.68270 X_3 + 0.01331 X_4 - 0.01967 X_5 - 0.00300 X_6 + 0.001767 X_7 \quad (VII)$$

where:

Y = number of vehicle trips per day in both directions between a zone and its central business district

X_1 = population of the study zone

X_2 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone

X_3 = number of passenger cars owned in the study zone

X_4 = two factor interaction of percent of population that are workers in the study zone by the number of people that are in the study zone

X_5 = two factor interaction of percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone

X_6 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of population that are workers in the study zone by the population of the study zone

X_7 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone.

The amount of variability (R^2) explained by this model was 91.7 percent with a sample size of 75.

Interzonal Vehicle Trips

A model for the number of vehicle trips per day in both directions for the zonal interchanges between the non-CBD zones in the study cities was evolved. The following model resulted:

$$\begin{aligned}
Y = & 796.2 - 0.1084 X_1 - 0.04275 X_2 - 133.7 X_3 - 6.223 X_4 \\
& + 15.29 (10^{-4}) X_5 + 20.84 (10^{-4}) X_6 - 0.7401 (10^{-2}) X_7 \\
& + 0.1018 (10^{-4}) X_8 - 0.5256 (10^{-5}) X_9 + 0.7234 (10^{-3}) X_{10} \\
& + 52.37 (10^{-6}) X_{11} + 1.262 X_{12} - 11.10 (10^{-10}) X_{13} \\
& - 3.564 (10^{-14}) X_{14} - 8.876 (10^{-10}) X_{15} - 0.3867 (10^{-11}) X_{16} \\
& + 0.1507 (10^{-6}) X_{17} - 0.1886 (10^{-6}) X_{18} + 1.443 X_{19} \\
& - 0.1514 X_{20} - 2321.1 X_{21}
\end{aligned} \tag{VIII}$$

where:

Y = number of vehicle trips per day in both directions for zonal interchanges between non-CBD zones.

X_1 = number of cars owned in the smaller populated zone.

X_2 = number of cars owned in the larger populated zone.

X_3 = distance in miles between the centroids of the two zones.

X_4 = angle in degrees between centroid of zone i and centroid of zone j with the vertex at the centroid of the central business district.

X_5 = two factor interaction of the population of the smaller populated zone by the percent of population under 34 years that are enrolled in school for that zone. This is a measure of the school enrollment for that zone.

X_6 = two factor interaction of the population of the smaller populated zone by the percent of workers in that zone.

This is a measure of the number of workers in that zone.

X_7 = two factor interaction of the population of the smaller populated zone by the straight line distance in miles between the centroids of the two zones.

X_8 = two factor interaction of the population of the larger populated zone by the percent of population under 34 years that are enrolled in school for that zone. This is a measure of the school enrollment for that zone.

X_9 = two factor interaction of the population of the larger populated zone by the percent of workers in that zone. This is a measure of the number of workers in that zone.

X_{10} = two factor interaction of the population of the larger populated zone by the straight line distance in miles between the centroids of the two zones.

X_{11} = two factor interaction of the number of passenger cars owned in one zone by the number of passenger cars owned in the other zone.

X_{12} = two factor interaction of the distance in miles between the centroids of the two zones by the angle in degrees between the two zones with the vertex at the central business district.

X_{13} = four factor interaction of population of a zone by percent of population under 34 years that are enrolled in school in that zone by population of the other zone by percent of population under 34 years that are enrolled in school of the other zone. This is a measure of the two factor interaction of school enrollment by school enrollment.

X_{14} = four factor interaction of population of a zone by median income of families in that zone by population of the other zone by median income of families in the other zone.

X_{15} = four factor interaction of population of a zone by percent of workers in that zone by population of the other zone by percent of workers in the other zone. This is a measure of the two factor interaction of workers by workers.

X_{16} = three factor interaction of population of a zone by population of the other zone by transportation study population.

X_{17} = three factor interaction of population of a zone by population of the other zone by percent using public transportation to work for the standard metropolitan statistical area.

X_{18} = three factor interaction of population of a zone by population of the other zone by the straight line distance in miles between the centroids of the two zones.

X_{19} = three factor interaction of the straight line distance in miles between the zone and the central business district, between the other zone and the central business district and between the two zones.

X_{20} = three factor interaction of the straight line distances in miles from the centroid of the zone to the central business district by the distance from the other zone to the central business district by the angle in degrees between the two zones with the vertex at the central business district.

X_{21} = two factor interaction of the population of the smaller zone by the percent of workers in that zone divided by the two factor interaction of the population of the larger zone by the percent of workers in that zone. This is a measure of the ratio of workers between two zones.

The amount of variability (R^2) explained by this model was 70.0 percent with a sample size of 269.

Truck Trips

Average daily traffic volume consists of passenger cars and trucks. Light delivery trucks, such as panels and pickups, are normally considered as passenger cars. Trucks include all buses, single-unit trucks, and truck combinations, that is, vehicles with dual tires on the rear axle. (4)

A simple regression analysis relating truck trips to total vehicle trips for all the cities was made and the relation is shown in Figure 4.

Conclusions

The trip prediction equations developed in this research were obtained from a sample of data available on fourteen major urban areas of less than one million population in standard metropolitan statistical areas. Certain travel pattern elements or characteristics may be

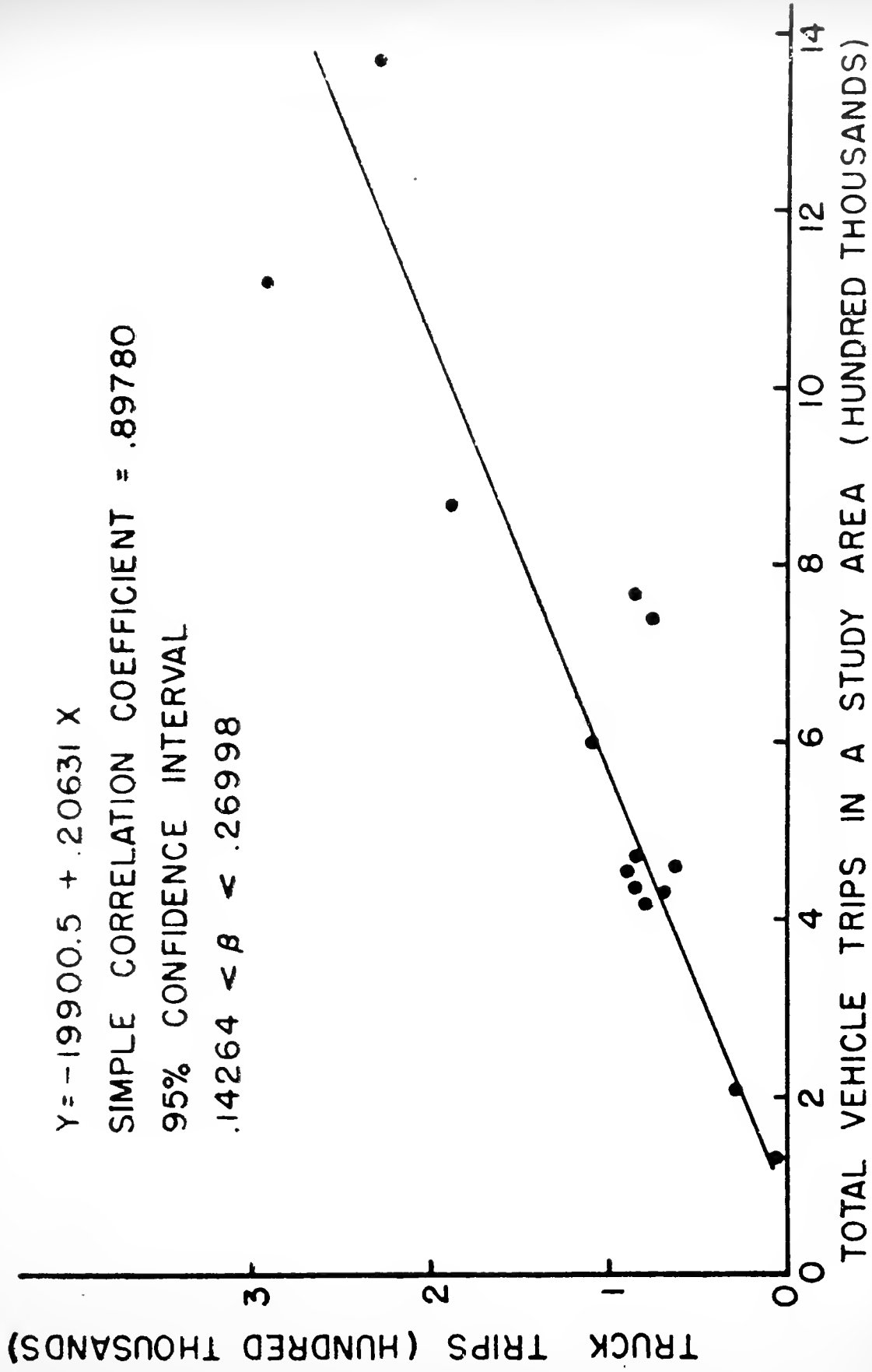


Fig. 4 Relation between truck trips and total vehicle trips.

estimated for similar urban areas by the use of the indicated models developed in this research. The models explained a large amount of the variability in the sample of travel pattern elements tested in fourteen cities and appear to be good predictors. These travel pattern elements or characteristics and the prediction models are:

1. The total number of vehicle trips per day - Model I.
2. The ratio of external vehicle trips per day to total vehicle trips per day - Model II.
3. The ratio of local vehicle trips per day to internal vehicle trips per day - Model III.
4. The number of vehicle trips per day to and from the central business district - Model IV.
5. The number of intrazonal central business district vehicle trips per day - Model V.
6. The total number of vehicle trips per day attracted and generated by each zone - Model VI.
7. The number of vehicle trips per day between a zone and the central business district - Model VII.
8. The number of interzonal vehicle trips per day between two zones, excluding the central business district - Model VIII.
9. The number of truck trips per day in a transportation study area can be estimated by the use of Figure 4.

Models for trip prediction will not supplant all field studies in urban areas but models are a tool which can assist in the understanding of transportation problems.

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